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**APPLICATION FOR LETTERS PATENT:**

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**Low Momentum Loss Fluid Manifold System**

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## **Low Momentum Loss Manifold System**

### **CROSS REFERENCE TO RELATED APPLICATIONS**

**[0001]**      None

### **STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT**

**[0002]**      Not related to this application.

### **BACKGROUND**

#### **Field of the Invention**

**[0003]**      The present invention relates generally to liquid cooling thermal management systems and more specifically it relates to a two-phase liquid cooling management system that provides economies of scale with consistent high performance through the use of a low momentum loss fluid manifold system.

## **Description of the Related Art**

**[0004]** Liquid cooling is well known in the art of cooling electronics. As air cooling heat sinks continue to be pushed to new performance levels, so has their cost, complexity, and weight. Liquid cooling systems provide advantages over air cooling systems in terms of heat removal rates, component reliability and package size.

**[0005]** Liquid cooling systems are comprised of many different species. Although each specie may have unique advantages and disadvantages, they are all designed to perform the same goal: remove heat from an electronic component. Generally, liquid coolant is placed in thermal contact with a component to be cooled wherein energy is transferred from the higher temperature component to the coolant. A pump circulates the liquid through the closed system, thus allowing the cooling fluid to continuously transfer thermal energy from the component to be cooled and to a desired location. Typically, the absorbed heat is removed from the cooling fluid through the use of a heat exchanger. Species of liquid cooling systems can be lumped into two categories: single-phase and two-phase. The "phase" signifies how the cooling fluid absorbs and exchanges energy.

**[0006]** Single-phase liquid cooling utilizes a pure liquid for absorbing heat from the component to be cooled. Energy is absorbed by the coolant through sensible heat gains. The temperature of the coolant increases as energy is absorbed according to well known engineering formulas. An example of a

single-phase liquid cooling system is described by U.S. Pat. No. 6,234,240. Due to the simple nature of single-phase fluid flow and sensible heat gains, single-phase liquid cooling solutions are fairly straight-forward to design and implement.

**[0007]** The preferred method of liquid cooling is two-phase. A two-phase system absorbs energy from the component to be cooled by means of latent heat gains of its fluid. The temperature of the coolant does not necessarily change, but rather part of the coolant is vaporized as energy is absorbed. The vaporized coolant is then transferred to a heat exchanger, or condenser, where energy is removed from the vapor causing it to transform back to a liquid state. An exemplary two-phase cooling solution is described by U.S. Pat. No. 5,220,804, which describes how atomization of the cooling fluid, along with vapor management within the spray module, provides high heat flux thin film evaporative cooling.

**[0008]** The advantages of two-phase cooling over single-phase cooling are significant. Due to the amount of energy needed to vaporize a liquid in comparison to the energy required to raise its temperature, two-phase systems provide the ability to have more compact components, require less input energy and provide higher heat removal performance than single-phase systems.

**[0009]** Although both single-phase and two-phase liquid cooling solutions provide many advantages over air cooling solutions, they also have drawbacks. One such drawback is that liquid cooling can be more expensive than air cooling. In the case of a single processor application, an air cooling heat sink may be

comprised of an aluminum extrusion and a fan. In the case of liquid cooling, for each processor, a pump, a heat exchanger, tubing, fittings, fluid and a thermal management unit are needed. Although the performance of liquid cooling may justify the increased cost over air cooling, liquid cooling a single processor may require a cost premium.

**[0010]** One of the ways to reduce costs of liquid cooling solutions is to cool multiple electronic components from a single closed loop liquid cooling system. In the case of a rack full of servers, many computer systems may be chained together. The result is a significant savings through economies of scale. Chaining electronic components together can be accomplished in two ways: parallel and series connections.

**[0011]** With series connections, the fluid is routed from one heat generating component to another, until all units have been cooled. Although this method is largely used with single phase systems, it can also be used with two-phase systems. A significant problem with series connections is that the cooling fluid is at a different thermal state at each electronic component along the chain. As one processor may go from a max power consumption state to an idle state, that processor may create a thermal cycle for the other processors in the system. Thermal cycling reduces component reliability.

**[0012]** With parallel connections, the fluid is routed from the pump directly to all components to be cooled. The fluid is also removed from the thermal management units via individual parallel branches. A prior art return system is

shown in Figure 2 of the attached drawings wherein each thermal management unit has a unique fluid path. Although this type of connection is used primarily with two-phase systems, it can be used with single-phase systems as well. Parallel connections remedy the disadvantages of series connections, but it too creates challenges.

**[0013]** A first challenge with parallel connections using two-phase flow is that the flow of fluid can be complicated. Vapor is significantly less dense than liquid and thus the mixture can create multiple flow patterns including: annular, slug and froth. The mode of flow can be difficult to predict and tests have shown the mode of flow to have a significant impact on the performance of a cooling system.

**[0014]** Another problem with parallel connections is that the numerous transitions can cause system back-pressures. Back-pressures, or restrictions downstream of a spray module, can cause an increased pressure level within a spray module. Increased spray module pressures decrease vaporization and overall heat transfer rates. In addition, back-pressures create system inefficiencies as the pump must perform additional work.

**[0015]** Yet another problem with parallel connections is that in many computer cooling applications, the locations of particular processors may not be fixed. The parallel connections of the cooling system must be created in a fashion that provides configuration flexibility.

**[0016]** Thus, there is a need for a two-phase parallel liquid cooling solution capable of cooling many electronic components in non-specific configurations. It is highly desirable for such a system to provide consistent cooling performance under a wide range of conditions.

## **BRIEF SUMMARY OF THE INVENTION**

**[0017]** In order to solve the problems of the prior art, and to provide a liquid cooling solution that allows multiple components to be cooled in parallel, a low momentum loss fluid manifold system has been developed.

The present invention is a two-phase liquid cooling system that cools a plurality of electronic components connected in parallel. A pump delivers a cooling fluid, as a liquid, to a supply manifold wherein it splits into distinct branch lines. Preferably, the branch lines feed coolant to individual spray modules. The liquid coolant removes heat from the components to be cooled through evaporation. The resulting liquid and vapor mixture exits the spray modules via return branches. Each individual return branch feeds into a return manifold at an acute angle. The acute angular transitions between the return branches and the return manifold provides low momentum losses and a more efficient system. In addition, the conservation of return fluid momentum in each of the return branches helps draw fluid from other return branches in the system.

**[0018]** These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, and accompanying drawings



## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0019]** In the course of the detailed description to follow, reference will be made to the attached drawings. These drawings show different aspects of the present invention and, where appropriate, reference numerals illustrating like structures, components, and/or elements in different figures are labeled similarly. It is understood that various combinations of the structures, components, and/or elements other than those specifically shown are contemplated and within the scope of the present invention:

**[0020]** Figure 1 is a block diagram of a two-phase thermal management system cooling with a plurality of spray cooling modules connected in parallel;

**[0021]** Figure 2 is a perspective view of a prior art return manifold connected to a plurality of perpendicular return branches;

**[0022]** Figure 3 is a perspective view of a return manifold with individual return branches feeding the return manifold at angles less than perpendicular and according to the present invention;

**[0023]** Figure 4 is a front view of a rack containing multiple chassis that contain electronic components to be cooled by a two-phase thermal management system; and

**[0024]** Figure 5 is a partial perspective view of an alternative embodiment low momentum loss return line system, showing flexible tubing return branches

connected at acute angles to a flexible return manifold, the connection between the branches and the manifold is created through the use of a plurality of splitter fittings.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0025]** Many of the fastening, connection, manufacturing and other means and components utilized in this invention are widely known and used in the field of the invention are described, and their exact nature or type is not necessary for a person of ordinary skill in the art or science to understand the invention; therefore they will not be discussed in detail.

**[0026]** Applicant hereby incorporates by reference U.S. Patent No. 5,220,804 for a high heat flux evaporative cooling system. Although spray cooling is herein described as the preferred method of two-phase cooling, the present invention is not limited to such a system. Spray cooling is only discussed in detail to provide a known preferred embodiment.

**[0027]** Now referring to Figure 1, a two-phase thermal management system **4** is shown. A cooling fluid (not shown) is pressurized by a pump **5**. An exemplary cooling pump **5** is described by U.S. Pat. No. 6,447,270. The cooling fluid may be any one of a wide range of commonly known dielectric or non-dielectric fluids, including but not limited to Fluorinert (a Trademark of 3M Company), hydrofluorether, and water mixtures. Cooling fluid travels from pump **5**, through a supply manifold **20**, and to a plurality of supply branches **21a**, **21b**, **21c** and **21d**. Fluid from supply branches **21a** – **21d** delivers the pressurized cooling fluid to a plurality of spray modules **10a**, **10b**, **10c** and **10d**. The preferred method of constructing and using spray module **10a** – **10d** is described by U.S. Pat. No 5,220,804 incorporated by reference to this application.

**[0028]** The '804 patent describes a spray module capable of high heat flux thin film cooling. Fluid is deposited onto a heated surface in a fashion that promotes the creation of a thin coolant film. The coolant film absorbs energy by through evaporation. The overall heat transfer of the module is partly a function of the thickness of the coolant film and the pressures within the spray module. Although it is highly desirable, in terms of efficiency, to have all the liquid transform into vapor within the spray module, the exit fluid typically has a quality less than 100 percent.

**[0029]** Referring back to Figure 1 and according to the present invention, the fluid leaving spray modules **10a – 10d** travels through a plurality of return branches **22a - 22d**, and into a return manifold **23**. Return manifold **23** delivers two-phase fluid to a heat exchanger **8** wherein the two-phase cooling fluid returns to a pure liquid state prior to re-pressurization by pump **5**.

**[0030]** Although four spray modules are shown in the accompanying drawings, the present invention is not limited to a certain number of spray modules within thermal system **4**. In fact, in datacenter type applications, tens to hundreds of spray modules may be connected in parallel. For each spray module there will be a corresponding supply branch and return branch.

**[0031]** Thermal management system **4** is ideally suited for applications where numerous components to be cooled are located in a given space. For instance, Figure 4 shows an equipment rack **30** commonly used in the networking or telecom industry. Chassis **12a – 12d** may be mounted to rack **30**

which is secured to a floor. Chassis **12a – 12d** may be any number of available electronic enclosures including: routers, hubs, switches, power supplies, multiplexers, optical transmission equipment and the such. Each chassis **12a – 12d** may be of a different height, but will typically be of a standard specification driven height. For instance, chassis **12a** may be four rack units in height, and chassis **12b** may be only one rack unit in height. The ability to use a wide range of chassis types within rack **30** provides the ability to construct a wide range of applications specific computing configurations.

[0032] Figure **4** is shown with thermal system unit **6** mounted below chassis **12d**. Preferably, thermal management unit **6** contains pump **5**, heat exchanger **8**, and any number of common liquid cooling system components, such as monitoring equipment, sensors, reservoirs, filters and the like. Thermal management unit **6** delivers pressurized single phase coolant to supply manifold **20** and in the direction of chassis **12d**. Along the length of supply manifold **20**, a series of supply branches **21a – 21d** are fluidly connected with a spacing corresponding to rack units. Each supply branch **21a - 21d** provides fluid to a corresponding chassis **12a – 12d**. Unlike the prior art, braches **21a – 21d** are fluidly connected to supply manifold **20** at acute angles. Fluid entering supply branches **21a – 21d** has a vector component in the direction of fluid travel in supply manifold **20** and provides the means for minimizing pressure losses between pump **5** and spray modules **10a – 10d**. Wherein the branches of a prior system (Figure **2**) may have single phase resistance coefficients (K factors) of

one to two, the acute angles between supply branches **21a – 21d** and supply manifold **20** provides individual resistances less than one.

**[0033]** Also located on rack **30** is return manifold **23**. Similar to supply manifold **20**, return manifold **23** is connected to return branches **22a – 22d** in a fashion that creates acute angles between them. Because the fluid flowing through braches **22a – 22d** and supply manifold **23** is two-phase, this acute angle provides significant system benefits. The fluid leaving return branches **22a – 22d** has a vector component in the direction of travel of fluid within return manifold **23** and provides the means for minimizing fluid momentum losses between spray modules **10a – 10d** and heat exchanger **8**. The acute angle formed between return manifold **23** and return branches **22a – 22d** also provides the means for reducing backpressures on spray modules **10a – 10d**.

**[0034]** Return manifold **23** is shown in more detail in Figure 3. Each individual return branch **21a, 21b, 21c** and **21d** is preferably connected to return manifold **23** through the use of a plurality of quick disconnect fittings **25a, 25b, 25c** and **25d**. Quick-disconnect fittings **25a – 25d** allow fluid to pass when a branch is inserted, but stops fluid from escaping once a branch is removed. Quick-disconnect fittings are widely available from companies such as Colder Products Company. Placing a series of valved fittings, such as quick-disconnect fittings **25a-25d**, along the length of supply manifold **20** and return manifold **23** with spacing corresponding to rack units further creates the means for providing chassis configuration flexibility within rack **30**. A wide range of chassis, of

varying height, may be installed even after rack **30** is installed in the field. Supply manifold **20** and return manifold **23** may extend the entire length of rack **30**, or just a portion if an application warrants. Supply manifold **20** and return manifold **23** may both be located on the same side of rack **30**, separate sides (as shown in Fig. 4), and either in the front or back side of rack **30**. It is also possible to have the vertical rails of rack **30** house return supply manifold **20** and return manifold **23**.

**[0035]** Optimal construction of supply manifold **20**, supply branches **21a – 21d**, return branches **22a – 22d** and return manifold **23** are application specific. For example, if space is limited in front of the rails of rack **30**, it may be desirable to have a square shape to supply manifold **20** and return manifold **23**. If supply manifold **20** and return manifold **23** are to be captured within the rails of rack **30**, then a round cross section may be desirable. Optimal sizing is a function of the number of thermal management units in the system, the type of thermal management system, the type of fluid used, and the heat generated by the components. In some applications it may be desirable to size return manifold **23** sufficiently to promote gravity induced liquid – vapor separation within. It may also be desirable to size return manifold **23** sufficiently to separate any non-condensable gasses from the cooling fluid. A controllable valve **29** located at the highest point of return manifold **23** could provide the ability to vent unwanted non-condensable gases from the system.

**[0036]**       ISR has verified the performance of the system using two 103 watt spray modules, a pump delivering roughly 20 p.s.i. of fluid pressure at 160 ml per minute, utilizing Fluorinert 5050 cooling fluid, and 1/4 inch diameter polyurethane tubing for supply manifold **20**, supply branches **21a – 21d**, return branches **22a – 22d**, and return branch **22**.     Although polyurethane tubing was used during testing, metallic materials are preferred for long term use with Fluorinert (a Trademark of 3M). Flexible polyurethane tubing is commercially available under the tradename Tygothane (a trademark of Norton Company Corp.)

**[0037]**       Figure 5, shows the alternative embodiment described above, wherein return manifold **23** is constructed from flexible tubing. A plurality of splitter fittings **26a** and **26b** are inserted into return manifold **23**. Splitter fittings **26a** and **26b** are commercially available in 45 degree angles and can be manufactured in angles less than 45 degrees. Fittings **26a** and **26b** may also have integral quick-disconnect features. The flexible tubing embodiment shown in Figure 5 provides the means for a low momentum loss manifold system capable of three dimensional shapes and configuration flexibility. The embodiment of Figure 5, may be used to connect chassis **12a – 12d** to return manifold **23** (as shown), but can also be used to connect, in parallel, multiple spray modules within a single chassis. Thus, cooling fluid may be collected within an enclosure from multiple spray modules via a first plurality of return branches, which is fed into a secondary plurality of return branches, which in turn is fed into return manifold **23**.



**[0038]** While the low momentum loss manifold system herein described constitutes preferred embodiments of the invention, it is to be understood that the invention is not limited to these precise form of assemblies, and that changes may be made therein with out departing from the scope and spirit of the invention. For example, return branches **22a – 22d** may be mounted perpendicular to return manifold **23**, but contain an internal baffle that alters the trajectory of liquid and vapor coolant leaving return branches **22a-22d** in the direction of flow within return manifold **23**. For further example, it should be obvious to one skilled in the art that spray modules **10a – 10d** may be global spray cooling modules each integral to a chassis or enclosure.